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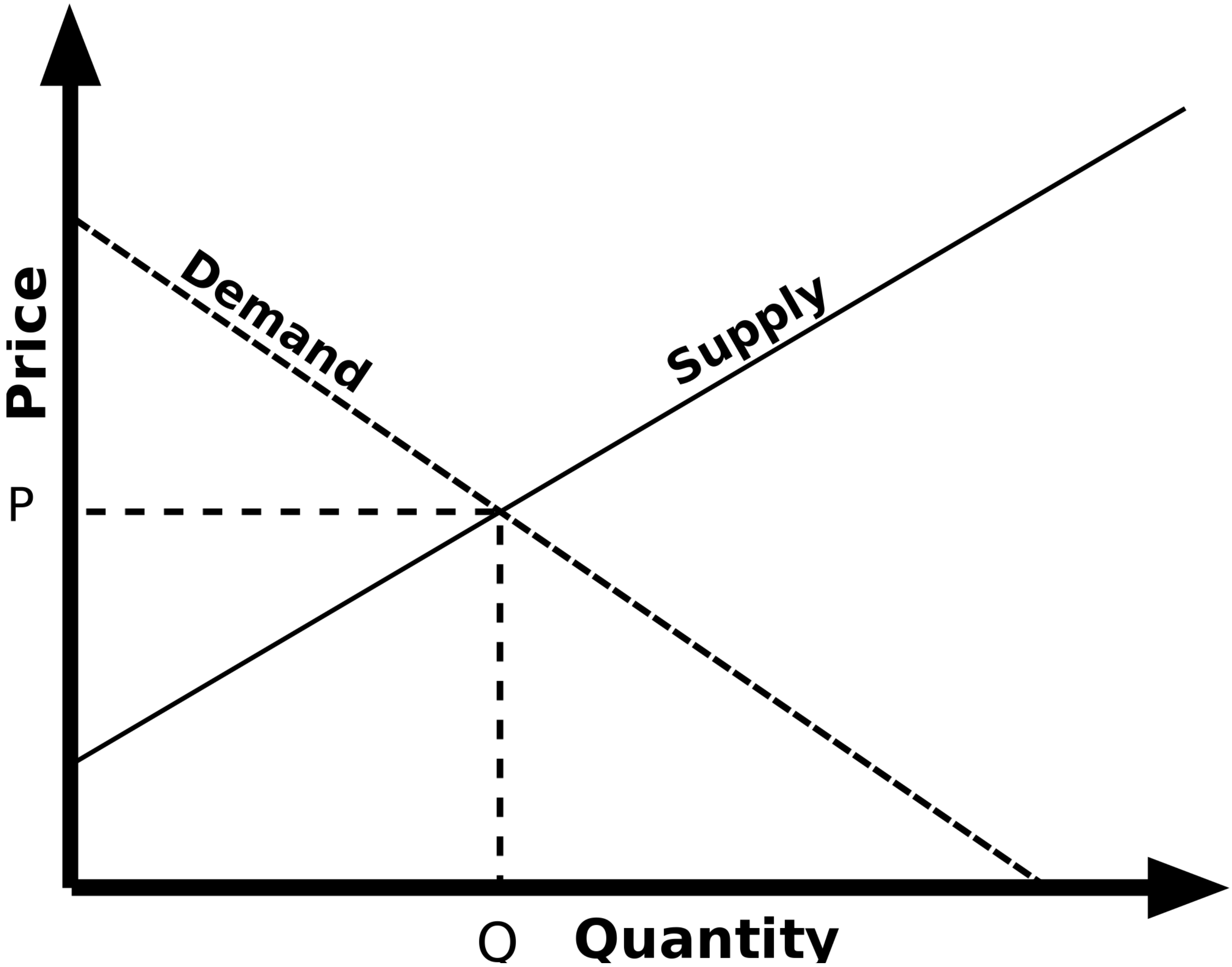

Models in Economics

by

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Preface

This note was written as teaching material for the course in philosophy of agricultural economics at Copenhagen University. The note introduces the theory of models as representations developed by Ronald Giere and others (Giere 1988, 2004; Giere, et al. 2006) and applies it to a case from agricultural economics. The aim is to deepen the students' understanding of the nature and uses of models in economics and encourage reflection.

It is of course not unproblematic to apply a theory developed to suit the natural sciences, particularly physics and biology, outside its intended domain. A critical, but open, mind should therefore be maintained throughout the reading of the text. For an alternative treatment of models in economics written for a similar audience see Reiss (2013), Ch. 7.

Acknowledgements

In the development of this note I had valuable help from Natalia Golubeva, Henrik Thorén and David McVicker.

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1 Introduction

Models play central roles in all research fields, including economics. They also take many forms. Some are highly simplified and general, others are very detailed and specific, many lie somewhere in between. Examples of very simplified and general models are found e.g. in macroeconomics where models representing the development of the economy in 'a society' as a function of very few variables are common. In such models, a number of variables that influence the economy in any given society are deliberately ignored to achieve a simple and widely applicable model. Other macroeconomic models are much more detailed and specific. The ADAM model developed by Statistics Denmark (2013), for instance, contains a multitude of variables and a detailed description of the relations between them. This has many advantages, but the price is that the model is very complex and only applies to one specific society; Denmark.

Despite, or perhaps because of their omnipresence and diversity we tend to take models for granted in our daily scientific work and not reflect on what they are and how they help us achieve the aims of science. This note seeks to make the reader reflect on the nature and uses of models in economics. More specifically, the goal of this note and the associated teaching is that the student should be able to:

Knowledge:

- Give examples of important models in economics.
- Give examples of the different purposes models serve in economics.

Skills:

- Identify central assumptions in a given economic model.
- Identify hypotheses, models, data and predictions in a given study.

Competences:

- Discuss the assumptions made in a given model in relation to the purpose of the model.
- Assess the reliability of the evidence for or against a given hypothesis.
- Discuss the uses of models in economics.

To achieve these goals, we start out with a brief discussion in Sec. 2 of the many different uses of models in economics. In Sec. 3 we consider the nature of models in more detail, including a recent case study. In Sec. 4 we discuss the important process of testing a model. Sec. 5 considers the application of the theoretical tools introduced in the previous sections.

2 The uses of models

Models are used in all aspects of economics, aiding the economist in achieving the goals of his or her practice. As discussed elsewhere (e.g. Reiss (2013), Ch. 1), these aims include:

- *Predicting* the development of economic phenomena
- *Understanding* the development of economic phenomena
- *Advising* non-specialists, including politicians, about the economic consequences of suggested economic interventions.

The "economic phenomena" that the economist wishes to understand and/or predict are often rather abstract things like inflation, GDP, or the costs and benefits of a given political initiative. Similar to e.g. the number of sides on a die they can be represented with mathematical variables, but unlike the number of sides on a die, the phenomena that economists typically strive to capture cannot be studied directly. Unlike the die, we cannot pick up inflation to investigate its various properties and see how it behaves. This is one of the reasons why it is so useful for us to represent economic phenomena with mathematical variables; it gives us something manageable to work with and helps us grasp certain aspects of the phenomenon in question.

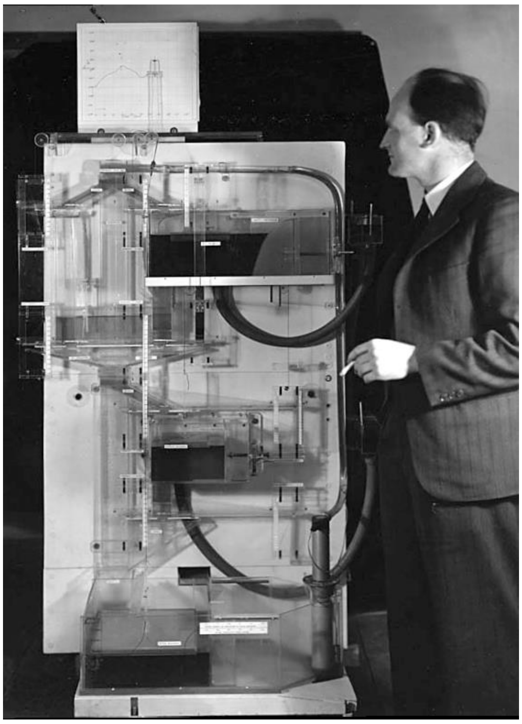

Figure 1: William Phillips and his MONIAC model of the UK economy. Source Wikimedia

Economists do not just represent phenomena with mathematical symbols. They use a range of things including graphs, diagrams and pictures as representations as well. In 1949, William Phillips even developed a fluid-mechanical model of the national economic developments in the UK (Fig. 1). This model, called MONIAC, used a flow of water between different tanks as a representation of the flow of money between different institutions.

Economists thus use several different types of models, sometimes for different purposes. An important question to consider is therefore what makes a model useful? Does this have anything to do with the truth or precision of the model? Does it even make sense to say that a model like Phillips' is true?

To answer questions like these, it helps to take a closer look at what a model actually is.

3 What is a model?

Above I used the terms ‘model’ and ’representation’ interchangeably. Models represent and representations are models. So a first step towards answering the question ‘what is a model?’ is to say something about representation.

Phillips’ MONIAC model represents the UK economy because Phillips and others *used* it as a representation of the UK economy. Had they used it to represent the French economy it would be a (perhaps less useful) representation of the French economy. Representations are thus the result of acts of representing. Humans and other creatures capable of intentional actions can chose to use something or someone as a representation of something else to achieve a certain purpose.

In court, lawyers represent their clients; they speak and act instead of the client. In your first aid class, a doll was used to represent a person with heart failure. In science, a variety of representations are constructed and studied instead of directly studying the phenomena that the models represent. So very generally:

Definition 1: A *representation* is anything that is used by someone to represent something else.

As we have seen scientific models can be many things, from concrete physical objects to abstract mathematics, but they have a common use; they are used by scientists as representations[1], and as such they help scientists achieve the goals of their practice.

Although models take many forms they all share certain characteristics, including:

1. All models are intended to be models of something.
2. All models are intended to be *similar* to what they are models of in certain respects and to a certain degree.
3. All models are *different* from what they are models of in certain respects and to a certain degree.
4. We can formulate statements about similarities and differences between models and that which they are models of. These statements can be true or false.

Let’s consider each characteristic in further detail.

Models are intended to be models of something: This point can sound almost trivial, but it allows us to make some important points.

[1] Of course this does not amount to a definition of a model, since I have not argued that all scientific representations are models (cf. Sec. 3.2).

First, not all models actually achieve the goal of representing a real phenomenon. The history of science contains many examples of models that were intended to be models of real phenomena, but these phenomena turned out not to exist.

In most cases however, models are actually models of something. We can distinguish between two different types of models: Models of *phenomena*, which is what we have focused on so far, and models of *data*. This distinction rests on the more fundamental distinction between phenomena and data.[2]

Somewhat loosely defined, *phenomena* are features of the world that exist independently of the individual researchers studying them.[3] Many phenomena, like the itch on my left shoulder, are utterly uninteresting to researchers, partly because they are utterly uninteresting to most other people as well. Researchers mainly tend to be interested in generalized phenomena that reoccur – shoulder itches rather than the itch on my shoulder – or specific phenomena that only happen(ed) once but are for some reason of particular interest to a wider audience. Examples could be the great depression in the 1930s or the economic consequences of introducing a specific change in the existing legislation.

Phenomena thus come in many forms from the very general to the more specific. Consider again inflation. Inflation occurs in many different societies and at different periods of time. Economists are in some cases interested in understanding concrete instantiations of inflation, e.g. the inflation in Denmark in the 1980s, but they also aim to understand inflation as a general phenomenon independently of the specific societies it occurs in.

As a general phenomenon, inflation cannot be studied directly. We can only study instantiations of inflation. As previously mentioned, this is one reason why researchers study phenomena through models rather than studying them directly. Another reason is complexity. Interesting phenomena are usually multidimensional and the result of an intricate interplay between multiple factors. To get an overview and better understanding of such complex phenomena it can be very useful to construct a simplified model.

Not all models are models of phenomena; some are models of data.

Very generally, *raw data* are the outcomes of *measurements*. When you think of measurements you might think of e.g. using a thermometer to measure temperature or a tape measure to measure the length of your sofa, but we also make measurements when we collect information on house prices, shopping habits, etc. More generally a measurement is a type of physical interaction between an observer and a phenomenon of interest, often aided by some form of instrument.[4] Data are rarely used in their raw form, but go through

[2] For a classic philosophical paper on this distinction see (Bogen & Woodward 1988).
[3] Of course social phenomena like those studied by economists do not exist independently of humans, but they do exist independently of the individual economist.
[4] For further discussion of measurement in economics see Reiss (2013), Ch. 8.

some sort of *data analysis*. Part of the data analysis is based on our knowledge of the interaction through which the data was obtained. For instance, we use this knowledge as part of the assessment of the quality of our data. Measurements can be imprecise or down right wrong, and it is therefore necessary to consider the possibility of error when analysing data.

A first step in data analysis is often to construct a model of the raw data. It could, for instance, be a bar chart like the one shown in Fig. 2, or a scatterplot. Which type of representation is chosen for the data model will often depend on what the data are used for and what the traditions in the specific field are.

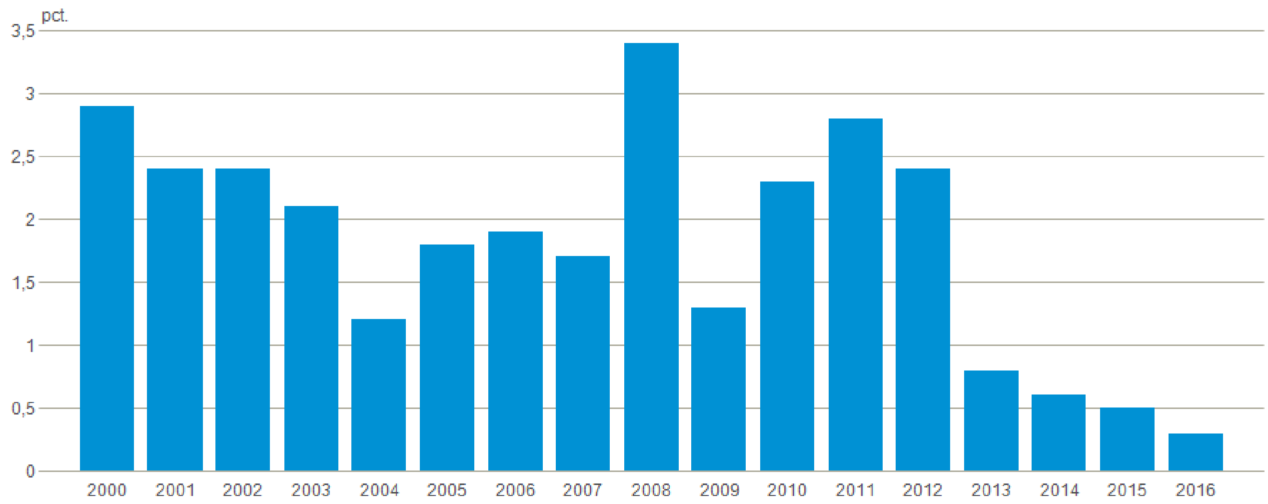

Figure 2: A data model representing data on the inflation in Denmark from 2000 to 2016. Source: Statistics Denmark.

Constructing a data model often requires a significant amount of analysis of the raw data that the model is based on. Maybe the raw data contain a lot of noise or erroneous measurements that need to be "cleaned out" before the data is useful. Maybe the data model will represent averages or medians calculated from the raw data.

Like models of phenomena, data models play a variety of roles in research. They can e.g. be used as a starting point for constructing models of phenomena. As discussed further in Sec. 4 data models also play very central roles when *testing* models of phenomena.

Models are intended to be *similar* to what they are models of in certain respects and to a certain degree: This is one of the reasons why models are useful. If a model of a phenomenon is similar to the actual phenomenon in a certain respect, we can learn something about that particular aspect of the phenomenon by studying the model. Similarity comes in degrees, and sometimes it is necessary to have a model that has a high degree of similarity with the modelled phenomenon, e.g. if we want to make precise predictions. However, the price of precision is often a loss of generality and simplicity, so in other cases we are happy to trade precision for simplicity and generality.

Just because a model is intended to be similar to a given phenomenon in a certain respect does not mean that the similarity is actually there. In scientific practice it is therefore important that models are tested to see if the intended similarities are in fact present (see Sec. 4).

All models are *different* from what they are models of in certain respects and to a certain degree: This is also part of the reason why models are useful. If the model was as complex as the phenomenon or the data that it is a model of, it would not help us. Simplicity is a key feature of many models, but the cost of simplicity is often a loss of respects in which the model and phenomenon are similar and the degree to which they are similar.

Differences between model and phenomenon or data are thus not a problem in themselves. Differences only become problematic when they prevent the researcher from achieving the aims of his or her practice.

We can say things about models that can be true or false: Models are representations and as such it seems irrelevant and perhaps meaningless to ask if they are true or false. Models obviously can be more or less useful, but can models be true? It seems that many models, including MONIAC, are not the kind of thing that we can meaningfully speak of as true or false. *Statements* can be true or false. Liquid flowing through a tube cannot.

Although it may not be meaningful to say that a model is true, it is certainly meaningful to say that statements describing similarities and differences between models and that which they are models of can be true or false.

To gain further insight into the nature and uses of models, let us consider a recent example of a model from agricultural economics.

3.1 An example

In 2015 researchers from the Department of Food and Resource Economics at Copenhagen University were asked by the Danish Ministry of Environment and Food to estimate the economic consequences of parts of a series of suggested changes to the national legislation on agriculture (Jacobsen & Ørum 2016). The results of these calculations came to play a significant role in the later political scandal known as "Gyllegate" (Goddiksen 2017). One consequence of these suggested changes to the existing legislation would be that many farmers would be allowed to increase the amount of nitrogen added to their fields in the form of fertilizer. In 2015 the existing regulation meant that farmers were allowed to add up to about 80% of the amount of nitrogen that would be optimal from an economic perspective. The changes in the regulation would mean that farmers would be allowed to add 100% of the economic optimum. To get an indication of the economic benefits of this regulatory change, the economists from Copenhagen University were asked to estimate the *average loss* that the existing regulation had caused crop-producing farmers per year.

The loss that the economists were asked to estimate is not directly measurable, e.g. as a deficit in a specific account. A model was therefore constructed in order to solve the problem.

First the economists had to choose an appropriate representation of the phenomenon of interest - the loss per year caused by the existing regulation. They could have chosen many things; a painting, a liquid (like Phillips), or a graph, but of course they chose none of these. The task given was to estimate a numerical value per year. We have a wonderful set of tools that can help us solve problems of this kind: Mathematics. However, if the problem is to be solved using mathematics, it is of little use to represent the phenomenon with a painting or a liquid. The most appropriate solution seems to be to represent the phenomenon with a mathematical function, $U(x)$, where x is the amount of nitrogen – measured in $\frac{kg}{ha}$ – that farmers are allowed to add to their land.

Already here we get a further indication of what makes a model useful: A model is useful if it allows the user to apply previously acquired knowledge and skills, in this case knowledge and skills in mathematics, to a given problem. Economists tend to be rather good at mathematics, and there is thus a strong tendency to make mathematical models in economics.[5] The same is true for many other research fields such as physics. But in other fields, researchers prefer different kinds of representations. Take a look in a biology textbook for instance, and you will find that the models presented in there are designed to aid a different kind of thinking that relies much less heavily on mathematics.

Once the researchers had chosen to represent the phenomenon of interest with a mathematical function, $U(x)$, the next step was to find an expression for this function. In this case $U(x)$ can be calculated as the difference between the income that the farmers *would have had* if they had been allowed to add the economic optimum of nitrogen, x_0, and the income they actually got under the current legislation. However we do not know what income the farmers would have had in the hypothetical situation where they were allowed to add more nitrogen to their fields, partly because we do not know if the farmers would actually make use of this possibility. To get on with the problem the researchers therefore introduced a *simplifying assumption* to their model:

Simplifying Assumption 1: Danish farmers are rational agents.

We know that this assumption is false (strictly speaking)[6], but that should not necessarily bother us, because the model is not intended to correctly represent the rationality of Danish farmers. It is intended to represent the loss that a certain piece of legislation caused Danish farmers with an acceptable degree of precision. As

[5] And it is of course partly for this reason that economists tend to be rather good at mathematics.
[6] Rationality is discussed further in Reiss (2013), Ch. 3-4.

long as our assumption does not prevent the model from fulfilling this purpose it does not matter whether it is true or false.

Once we have added assumption 1 it follows that farmers will always add the economically optimal amount of nitrogen to their fields, unless the law dictates a lower amount, in which case they will add this amount. We can now write $U(x)$ as:

$U(x) = S(x_0) - S(0{,}8x_0)$ (1)

Where $S(x)$ represents yearly average surplus as a function of x .

To solve equation (1) we of course need an expression for $S(x)$. Once we have that, we can, hopefully, differentiate it and find that it has a relevant maximum, and thus determine x_0. Once we have that, the problem is solved.

$S(x)$ can be written as:

$S(x) = \sum_{n=1}^{N} a_n(I_n(x) - E_n(x))$ (2)

Where I_n is the average yearly income, and E_n the yearly average expenses pr. ha for a particular crop, and a_n is the area on which the crop is grown. To get an expression for $S(x)$, we thus need expressions for I and E for each type of crop grown in Denmark as functions of x.

An important term in E is the expenses that farmers have when buying fertilizer. This can be written as the average prize pr. weight of fertilizer, b, times x. There are other expenses that could be written into E as well, including expenses for tractor fuel, irrigation, etc. However, the researchers chose to ignore these further terms and thus introduced an additional simplifying assumption:

Simplifying assumption 2: $E_n(x) = bx$

Like *Simplifying Assumption 1* this assumption is strictly speaking false, but that does not matter for our current purposes. The terms we have ignored are arguably independent of x and thus do not matter when determining x_0 , and in (1) they would cancel out anyway, if they were added.

I also has multiple terms. It obviously depends on the average yield, $Y(x)$, that a farmer can harvest pr. ha depending on how much nitrogen they are allowed to add to their fields times the average price pr. weight, c, that they can sell their harvest for. However, for some crops, particularly wheat, income does not only depend on quantity; it also depends on quality. More specifically the price of wheat depends to some extent on the protein content, P, which in turn depends on how much nitrogen was available when the wheat was growing. $I_n(x)$ can thus be written as:

$I_n(x) = cY_n(x) + dP_n(x)$.

$Y_n(x)$ and $P_n(x)$ can be estimated from data models derived from field experiments where the amount of nitrogen available to the crop is varied across otherwise similar fields. The exact expressions of $Y_n(x)$ and $P_n(x)$ for the different crops grown in Denmark vary from field to field depending on, among other things, the type of crop in the field in the previous year, and the type of soil in the particular field. The precise expressions for $I_n(x)$ are thus very complex and currently unknown as we do not have expressions for $Y_n(x)$ and $P_n(x)$ for every type of crop grown on every type of field in Denmark. To be able to get to a solution at all, researchers therefore had to make one further simplifying assumption:

Simplifying assumption 3: $I_n(x)$ can for each crop be approximated using expressions for $Y_n(x)$ and $P_n(x)$ obtained from field experiments on wheat grown on clay soil after rapeseed.

Unlike *Simplifying assumption 2* this assumption clearly affects the precision of the model in a relevant way, but it allowed researchers to get to an approximate result rather than no result at all.

The economists obtained the expression for $I(x)$ and $P(x)$ that they needed from colleagues in Aarhus. Luckily, both were second-degree polynomials, $ax^2 + bx + c$, with a negative a so they were both differentiable and had a maximum. From here on, solving the problem is a simple question of mathematics and plugging in the numbers. In their report, the economists reported that they had found that the current legislation had resulted in an annual loss of approximately 0,6 to 1,0 bn. kr. or between 1,3 and 1,8 bn. kr. depending on the numbers that you plug into the model and what adjustments you make to compensate for the error made in *Simplifying assumption 3*.

3.2 Summary

Section 3 introduced a number of concepts and ideas concerning models as representations. They are summarized in Box 1. We saw that models take many forms and are used for several different purposes. What brings them all together is their use as representations.

In section 3.1 we discussed an example of a very specific model developed within agricultural economics to answer a specific question posed by the Danish Ministry of Environment and Food. The case illustrates how the choice of representation depends on our interests and existing knowledge and skills. It also illustrates that part of the usefulness of models is that they are simpler than the phenomena they are models of, and that researchers deliberately simplify their models by adding simplifying assumptions to their models.

The case further illustrates that although all models are representations, it is perhaps not all representations that are models. Equation (1) is a representation, but is it a model? To some extent this is a matter of definition, but it seems that what economists tend to call *models are often larger collections of* *representations and assumptions that are related to each other in a more or less logical way.* In a way, then, models are representations made up of representations and assumptions.

Box 1: Key terms from Sec. 3

Phenomena: Features of the world that are independent of the individual researchers studying them. The phenomena studied by economists are often abstract and/or general which makes them hard to study directly.

Measurement: A physical interaction between an observer and a phenomenon performed to gain information about the phenomenon.

Raw data: The outcomes of measurements.

Representation: When someone uses X to represent Y, X becomes a representation of Y.

Model: Models are representations. Theoretical models in economics tend to be collections of representations and assumptions connected in a more or less logical way.

We distinguish between **models of phenomena** and **models of data.**

Models and the modelled phenomenon or data have both **similarities** and **differences**. Both aspects are important in making models useful to researchers.

4 Testing models of phenomena

The usefulness of a model of a phenomenon is highly dependent on it having relevant similarities with the phenomenon of which it is a model. To find out whether a model has the similarities and the precision that we need it to have in order to be useful for a given purpose, it is necessary to *test* the model. To many, the core characteristic of a scientific practice is exactly that similarities between models (or theories more generally cf. the appendix) and phenomena are not just postulated, but that serious efforts are made to test the models through empirical research.[7]

In order to test whether a model has the similarities and the precision that we expect, we must of course first specify what similarities we are looking for. Such a specification is an example of a *hypothesis*.

4.1 Hypotheses

Very generally:

Definition 2: A hypothesis is a statement, expressing what we expect to be the case in the world.

An example could be:

Hypothesis 1: The inflation in Denmark will be constant over the next five years.

When we speak of scientific testing, we often speak of testing hypotheses rather than models, but as we shall see one does not exclude the other. In fact we test models by testing hypotheses, and we often test hypotheses to test models.

Interesting hypotheses rarely fall from the sky. They are derived from our existing knowledge, our existing models. In fact this is often what makes a hypothesis interesting. A researcher could easily formulate hypothesis 1 as a wild guess. In fact that is what I just did. Such a wild guess might turn out to be correct. However, this hardly shows that the researcher is able to reliably predict the development of inflation, and adds very little to our understanding of inflation, and thus helps us little towards the aims of economics.

Had hypothesis 1 been derived from a model of inflation, then we would not only have learned that the hypothesis is true. We might also have some indication of *why* the inflation behaved the way it did, and have a way to predict inflation over other periods of time. Hypotheses derived from models are thus often the most interesting to test, because they not only potentially give us a new piece of knowledge, they also tell us something about the usefulness of the model that they are derived from.

[7] This also means that there is a limit to what we can make scientific models of. A model that represents something that is inaccessible to empirical research cannot be tested, and is thus according to this view unscientific. As discussed by Reiss (2013, Ch. 3), this view has created some controversy in microeconomics where models representing *preferences* are common. The problem is that preferences are mental states, which are very hard to investigate empirically, and some argued that many microeconomic models are thus unscientific.

A hypothesis derived from a model will usually specify a similarity that we expect to exist between the model and the modelled phenomenon. Very generally they will have the form:

Hypothesis general form: Model x is similar to phenomenon y in respects z with precision w.

Researchers rarely formulate their hypotheses in this stylized way, but if you go through an article presenting the results of a hypothesis test, you will usually find all the elements somewhere.

Once a hypothesis has been derived from a model, the challenge is to somehow find out whether or not the hypothesis is true. The hypothesis speaks of a similarity between a model and a phenomenon. The easiest way to test the hypothesis would thus be to compare the model and the phenomenon directly. However, this is rarely possible in economics, or in any other science for that matter, due to the abstract nature of the phenomena studied. If it was possible to e.g. pick up the inflation and directly compare it to our model of inflation in order to test hypothesis 1, we probably would not bother to make the model in the first place!

Because economics deals mainly with abstract phenomena, we face a significant challenge when testing the hypotheses that can be derived from our models; the hypotheses speak of similarities between model and phenomenon, but we cannot directly assess whether this similarity exists because we do not have direct access to the phenomenon. However, we do have indirect access to the phenomenon. Through *measurements* we can collect *data* that give us valuable information about the phenomenon. To test our hypothesis we must therefore translate it into a statement about these data. Such a statement would be an example of a *prediction*.

4.2 Predictions of data

Very generally:

Definition 3: A prediction is a statement describing what we expect to be the case if a given model (or set of models) of a phenomenon is similar to the modelled phenomenon in the respects and to the degrees hypothesised.

When we make predictions we thus (tentatively) assume that our model works and investigate the results that can be obtained using the model.[8] In Sec. 3.1 we saw how a model was constructed and used to predict the average yearly loss that a certain piece of legislation caused to Danish farmers. This is an example of a prediction of a phenomenon.[9] The construction of models that can reliably predict economic phenomena is an important aim of economics (cf. Sec. 2).

[8] Note that Definition 2 says nothing about *when* we expect something to be the case. *Post*dictions - predictions of past phenomena – are thus a specific type of prediction according to Definition 3.

[9] What is the difference between a prediction of a phenomenon and a hypothesis? Although the two can be hard to distinguish formally, there is often a difference in practice. Hypotheses are often formulated in order to be tested. Predictions of phenomena are often made for other purposes. The result that the researchers reached in the case

In addition to predicting phenomena, models can be used to generate *predictions of data*, i.e. what we expect the outcome of specific measurements to be if a given model is similar to the modelled phenomenon in the respects and degrees that we have hypothesised. Predictions of data are rarely predictions of raw data however. In practice a prediction of data will describe expected characteristics of a data model generated from the raw data. If we hypothesise that there be proportionality between two variables, we would thus predict that if we generate a scatterplot of our data, they would to a good approximation lie on a straight line.

Generating predictions of data requires a good understanding of the model we are working with, but also an understanding of how the measurements are made, the specific circumstances under which they are made, and the specific way they are processed from raw data to data model.

Contrary to hypotheses, predictions of data thus speak directly about data – usually in the form of a data model - and can therefore be compared directly with data. They can thus serve as the link between hypotheses and data.

4.3 Comparing predictions of data and models of data

Once a prediction has been made and data has been gathered and processed into a data model, the two can be compared. The comparison can have (at least) three possible outcomes:

1. The prediction and data do not match
2. The prediction and data do match
3. The outcome is unclear

The last option is frustratingly common and can be due to many things including lack of relevant data or vagueness in the model. However, we will not discuss it further here.

If the prediction and data do not match then the test of our hypothesis has not turned out the way we expected. However, we cannot conclude that our hypothesis is false. We can only conclude that at least one error has been made. The error could lie in the hypothesis –the world may not be the way we think it is, but it could also lie in the raw data – as a measurement error, or in the data model e.g. as an error in the statistical analysis performed on the raw data, or it could lie in the reasoning from hypothesis to prediction. Finding out where the error lies can be a long and tedious process, but if it is eventually established that the prediction was correct, and that the data were reliable, then the only remaining explanation of the mismatch between data and prediction is that out hypothesis was false.

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described in Sec. 3.1 exemplifies a prediction of a phenomenon. The purpose of making it was not to test it, but to provide the ministry with an answer to the question they had posed.

A match between prediction and hypothesis may of course also be due to an error in the data or in the generation of the prediction, so a match between prediction and data does not automatically mean that our hypothesis is true. In fact, even if the possibility of error in data and prediction can be reasonably ruled out, we still cannot be sure that the match between data and prediction is positive evidence for our hypothesis. For what if we could generate exactly the same prediction from an alternative model and thus an alternative hypothesis?

4.4 Alternative hypotheses

In his influential essay *A Methodology of Positive Economics* Milton Friedman concluded: "If there is one hypothesis that is consistent with the available evidence, there are always an infinite number that are." (Friedman 2007/[1953], p. 150). Friedman continues:

> "For example, suppose a specific excise tax on a particular commodity produces a rise in price equal to the amount of the tax. This is consistent with competitive conditions, a stable demand curve, and a horizontal and stable supply curve. But it is also consistent with competitive conditions and a positively or negatively sloping supply curve with the required compensating shift in the demand curve or the supply curve; with monopolistic conditions, constant marginal costs, and stable demand curve, of the particular shape required to produce this result; and so on indefinitely. Additional evidence with which the hypothesis is to be consistent may rule out some of these possibilities; it can never reduce them to a single possibility alone capable of being consistent with the finite evidence." (p. 150)

Friedman here points to the classic problem of *underdetermination* of models by evidence (Stanford 2013). No matter how much data we collect the amount will always be finite, and there is always an infinite amount of models that will fit a finite amount of data, just as there is always an infinite amount of curves that go through a finite set of points.

Underdetermination raises problems at two different levels. At the more practical level, it means that we cannot conclude that a hypothesis is true just because it has led to a prediction that turned out to be in accordance with data. We would have to make the additional step of ruling out other plausible models that could predict the data just as well. This requires that we develop a test where there is a measurable difference in the outcomes predicted by the competing models. In practice, there is rarely more than a few viable competing models available at any given point in time, but it can still be a significant challenge to discern between them.

At a more philosophical level, underdetermination raises important questions about what it means for a model to be viable, i.e. what characterizes a model that economists are willing to consider to be a serious alternative to an existing model *apart from the fact that it fits the available relevant data*. A simple view of science says that it is the data and the data alone that dictates which models researchers chose to work with, but as Friedman points out this cannot be true even in an ideal world.

Friedman himself suggests two concepts - *simplicity* and *fruitfulness* - that arguably play important roles when economists choose their models. These concepts, which can be very difficult to define, have also been shown to play important roles in model choice in the natural sciences (Kuhn 2012).

4.5 Summary

The key terms introduced in Section 4 are summarized in Box 2.

Box 2: Key terms from Sec. 4

Test: A systematic process aiming to investigate a hypothesis.

Hypothesis: A hypothesis is a statement expressing what we expect to be the case in the world. Hypotheses are commonly derived from models, and tests of hypotheses commonly made to assess the usefulness of a given model for a given purpose.

Prediction: A prediction is a statement describing what we expect to be the case if a given model (or set of models) is similar to the modelled phenomenon in the respects and to the degrees hypothesised.

Alternative hypothesis: A hypothesis, perhaps derived from a different model, that is equally consistent with the relevant available data as the hypothesis being tested.

Underdetermination: The choice among competing hypotheses is underdetermined by data in the sense that it is always possible to construct an infinite amount of models that fit the data available.

Most importantly, Sec. 4 introduced the process of testing a model. This process is summarized in Fig. 3, except for the important final part, where we consider alternative hypotheses.

Note that Fig. 3 only represents the key elements in the test of a model. It does not suggest a specific *order* in which these elements should be obtained. It is thus not a recipe for doing research, but simply a model of the key elements involved in the test of a model.

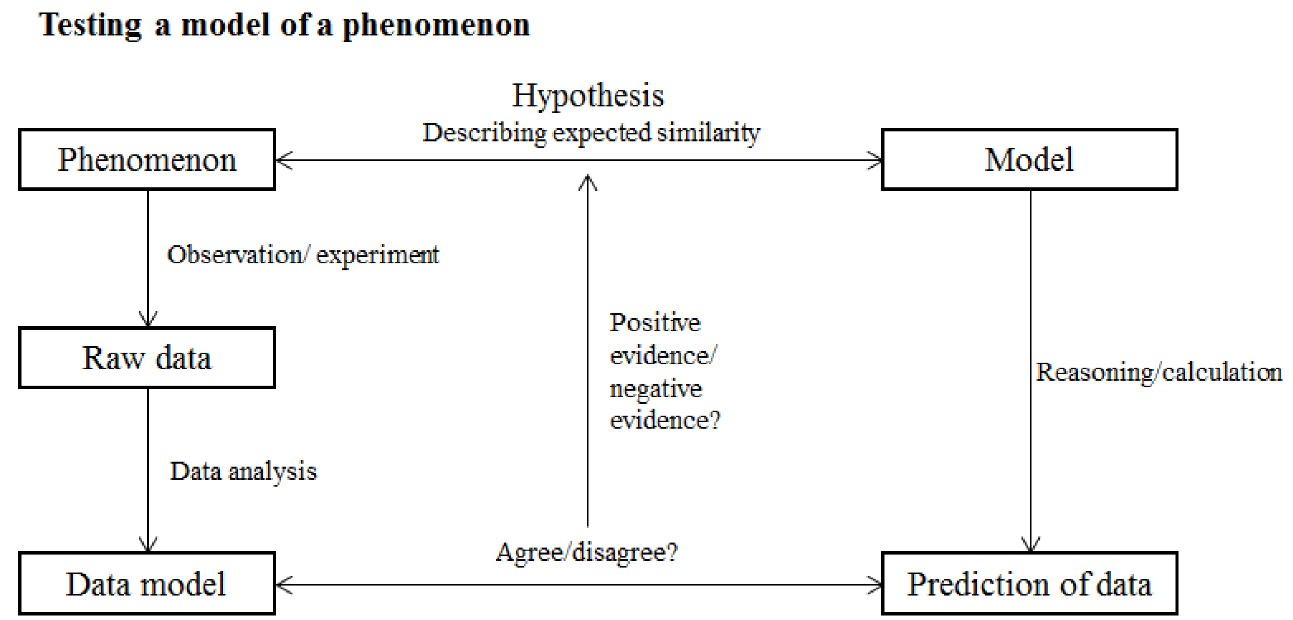

Figure 3: Testing a model of a phenomenon. To test a model of a phenomenon a hypothesis must be formulated. From the hypothesis a prediction is derived. The prediction is compared to a data model derived from raw data obtained through measurements. Disagreement between prediction and data model can be negative evidence for the hypothesis, but can also be indicative of other errors. Agreement between prediction and data model can be positive evidence for the hypothesis as well as competing hypotheses.

5 Perspectives

What is the use of Fig. 3, if it cannot tell us how do to research? Apart from providing a deeper understanding of tests in science in general and in economics in particular, Fig. 3 can be used to *assess the quality of a test*, be it a test you have performed yourself or one performed by others and presented to you, e.g. in a research article. To do so for a given test, a first step could be to identify the major elements: model, phenomenon, hypothesis, raw data, data model and prediction. Some of these will be explicitly stated in a research article, others will not, but it will be useful to get them into the light. A next step could be to consider how those who performed the test got from one element to the other. How was the prediction derived? Is the argument sound? If not, this could compromise the test. How were the raw data generated? Was the method appropriate? If not, this could also compromise the test. How were the raw data transformed into the data model? The answer is usually some form of statistical analysis, and there are lots of critical questions that you can ask about these. Finally, if the data model and the prediction of data agree it could be positive evidence for the hypothesis being tests, but it will be necessary to consider the possible alternative hypotheses before jumping to conclusions.

Appendix: Models, theories and laws

In the main text, I focused exclusively on models. I claimed that models are important in economics, and probably no economist would disagree with that. However, it might be objected that my exclusive focus on models has meant that other important theoretical entities – especially *theories* and *laws* – have been underemphasised. So for completeness, let us briefly consider how laws and theories fit into the framework introduced above.

5.1 What is a theory?

One of the most cited papers in economics is Kahneman and Tverky's (1979) *Prospect Theory: An analysis of Decision under Risk*. The paper was one of the main reasons why Kahneman was awarded the 'Nobel Prize' in economics in 2002. The title indicates that the paper presents a theory of how decisions are made under risk. Looking at the contents, it also seems that the paper presents a number of related models. The core of the paper presents a model of the general phenomenon. Following this models of more specific cases are introduced. The more specific models are developed from the general model, e.g. by specifying the value of certain variables. The paper ends by considering how the core model can be extended and adapted to account for a broader range of decision problems. Thus, the theory that Kahneman and Tversky present in their paper consists primarily of a set of related models. The models are related in the sense that they deal with related phenomena, share a set of core assumptions and the more specific models are developed from the more general models.

There has been much debate among philosophers over the nature of theories. Very roughly, two competing approaches can be identified: The *semantic* approach and the *syntactic* approach (Van Fraassen 1980).

The syntactic approach is the oldest and holds that scientific theories are in essence language things; collections of statements – axioms, theorems, simplifying hypotheses, laws – that have an internal logical relation. One advantage of this is that it means that it makes sense to consider whether a theory is true or false because it is the kind of thing – a language thing – that can be true or false.

Proponents of the semantic view do not deny that parts of theories are formulated in language, but they deny that theories are *just* language things. Rather, they argue based on analyses of how theories are presented and used in scientific practice that theories are best conceptualized as collections of models. This means that theories, like models, should rather be thought of as being more or less useful rather than being more or less true[10].

[10] Although the usefulness of a model may depend heavily on the extent it can be used to generate true hypotheses.

According to the semantic approach we have thus learned a lot about the nature and testing of scientific theories in the previous discussion on the nature and testing of models. For what does it mean to test a theory? It simply means testing one or more of the models that make up the theory.

5.2 What is a law?

The nature of laws in the natural and social sciences is another topic of debate and disagreement within the natural and social sciences themselves and within philosophy of science (for an introduction see e.g. Cartwright (2003)). Some hold that the laws of nature and the laws of economics are fundamentally different, e.g. that the laws of nature are universally true whereas the laws of economics are only true *ceteris paribus*. Others argue that all laws come with *ceteris paribus* clauses and the laws of nature and society are thus not fundamentally different. Part of the disagreement probably stems from the fact that what some people call laws, others call principles, definitions, axioms or something else. The semantic approach to theories recognizes that the role of things called laws vary greatly; some simply seem to be theorems with a fancier name. Other laws are generalizations that were perhaps once formulated as a hypothesis, but now have a special status within a theory, which means that they are not really questioned or tested anymore. Rather, they help define when the theory is applicable.

Consider the law of supply and demand originating from the theory of microeconomics. In one formulation it states:

Law of supply and demand: In a perfect market, the price and available quantity of a given good will reach market equilibrium.

We can in principle predict the market equilibrium as the intersection between the supply and demand curves.

The law is formulated like a hypothesis, but does it *function* as a hypothesis? Perhaps not. For what would happen if we found a market that seemed to be sufficiently close to being a perfect market for the law to apply, but where the law did not hold? Would we then conclude that the law/hypothesis was false? Or would we rather conclude that the market was not really a perfect market after all? If the latter is the case, then the law of supply and demand can be seen as an, *in practice*, partial definition of when a market is sufficiently close to being perfect for the theory of microeconomics to apply to it. So, *in practice*, the law of supply and demand holds for perfect markets, and actual markets that can be considered approximately perfect are characterized partly by following the law of supply and demand. In such a situation the law is not so much a hypothesis that might turn out to be wrong, but a partial definition of some of the central terms in microeconomics.[11] This also means that discarding or drastically reinterpreting the law would have drastic consequences for the entire theory. It would perhaps amount to a *scientific revolution* (Kuhn 2012).

In sum laws in economics are probably many different things. Some are simply very well established hypotheses that can be used to solve a big variety of problems. Others may have an even more elevated function as underlying assumptions for an entire theory and serve as partial definitions of the area application of said theory.

[11] Thomas Kuhn (2012) argued, based on a detailed historical analysis, that Newton's laws should indeed be viewed as partial definitions of central terms like force and acceleration that are central to the theory of Newtonian mechanics. They also help us distinguish between "Newtonian", "relativistic" and "quantum" phenomena. A phenomenon is Newtonian if they can be adequately described using Newton's laws.

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